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Predicting the impact of seabed uncertainty and variability on propagation uncertainty

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Uncertainty in seabed properties can lead to substantial uncertainties in acoustic propagation, of order tens of dBs. During this project, substantial progress was made in 1) quantifying seabed uncertainties, by developing an advanced seabed measurement technique and powerful commensurate methods to estimate the uncertainties and 2) predicting the effect of those effects on propagation by development of a theory that illuminates the effects of seabed variability and uncertainty on propagation uncertainty.

INTRODUCTION

Uncertainties in acoustic performance prediction lead to the inability of the Fleet to make judicious decisions about tactics and employment of resources. Seabed variability is one environmental condition that leads to prediction uncertainty. As an example of the importance of the seabed in performance prediction, consider the results of [1] where TL predictions (from existing water column and seabed databases) showed biases of order tens of dB with respect to measurements. Most of these errors were traced to limitations in the present generation of seabed databases; water column databases were relatively robust. This is not to say that the seabed databases are poor everywhere; it is simply to underscore the point that 1) knowing the seabed properties is critical to naval operations involving passive (or active) sonar: tens of dBs are at stake and 2) the ability of the community (6.1-6.4) to capture seabed properties and associated spatial variability is still quite limited.

The Quantifying, Predicting, and Exploiting (QPE) Uncertainty DRI has as its fundamental tenet that in any strategic situation, environmental parameters will never be known in sufficient detail to enable a perfectly accurate acoustic prediction. Thus, the goal is to provide the machinery to be able to quantify the uncertainty associated with that prediction. The focus in this research was the impact of the seabed on propagation uncertainty.

LONG TERM GOAL

Develop capability for quantifying, predicting and exploiting (QPE) the impact of seabed uncertainty on sonar system performance.

OBJECTIVE

The objective was to develop both measurement and inversion techniques in order to build a 2D geoacoustic uncertainty model (2D-GeUM) over an operationally significant area.

APPROACH

In order to predict the impact of seabed geoacoustic uncertainties and variability on propagation uncertainty along a radial of interest, a 2D geoacoustic uncertainty model (2D-GeUM) is required. Such a model quantifies depth- and range-dependent geoacoustic properties and their uncertainties over the area of interest. For the QPE experiment, the ~50 km x 50 km area of interest was defined off northeast Taiwan, including part of the Chilung shelf, the East China Sea shelf and upper slope. The original approach included a combination of direct-path wide-angle seabed reflection measurements and geologic modeling as the basis for generating the 2D-GeUM. The wide-angle reflection data were to be collected at multiple sites in the QPE experiment area in FY09. However, severe weather, equipment problems, and limitations of the research vessel prevented the requisite data from being acquired.

In lieu of this, the approach was to:

1. advance experimental techniques for measuring geoacoustic properties and their spatial variability in support of propagation prediction
2. develop methods to estimate geoacoustic uncertainty
3. advance theoretical understanding of the impact of seabed variability on propagation uncertainty,
4. apply the theory to the experimental geoacoustic uncertainties to examine propagation uncertainty.

RESULTS

The results have been extensively reported in the peer-reviewed literature and in conferences (see references and publications below). A summary of key advances follow.

Measurements:

- Developed an advanced measurement technique using an autonomous undersea vehicle with a towed source and receivers, see Ref [2]. This technique directly probes 2-D geoacoustic spatial variability at high spatial resolution along the track. The vertical resolution, $O(10^{-2})$ m, is a function of the bandwidth, source-receiver offset, and frequency resolution. The lateral resolution, $O(10^{1})$ m, is a function of geometry and frequency (via the Fresnel zone). Significantly, the method greatly reduces the undesirable effects of uncertainties caused by oceanographic temporal and spatial variability. Measurements were conducted in the Straits of Sicily in collaboration with the NATO Undersea Research Centre.

Quantifying Uncertainty:

- Collaborated with University of Victoria (Jan Dettmer and Stan Dosso as leads) to develop inversion methods for quantifying geoacoustic properties and their uncertainties, Refs [4]-[7]. Transdimensional approaches which can search over model space as well as parameter space were applied to both simulated and measured data. The results show a great deal of promise for application to advanced high spatial resolution measurements as developed in [2].

Theory, Predicting Uncertainty:

- Developed an intuitive theoretical expression for propagation in a waveguide with range-dependent seabed properties, Ref [3]. The importance of the theory is that it provides some deep insights and predictive capability into how propagation uncertainties are controlled by seabed spatial variability. A significant result is that the propagation uncertainty is dominated by uncertainties in the reflection coefficient, and specifically the geometric mean of the magnitude of the reflection coefficient. Generally, the uncertainties from the cycle distance due to uncertainties in the reflection phase are modest. It was also shown that the largest propagation uncertainties are due to the softest sediments or equivalently those with the lowest reflection coefficients. In other words, propagation uncertainties are driven by the lower bound in the uncertainty of the reflection coefficient. One surprising result was that in some instances, e.g., narrowband propagation over some layered seabeds, the seabed range-dependence may actually reduce the uncertainties (due to the averaging of layer resonance effects).

IMPACT/APPLICATIONS

The successful development of 2D geoacoustic uncertainty models has very broad implications for uncertainty estimation in the ocean acoustics community. In some ways, the data from the Straits of Sicily offer greater potential for understanding uncertainty than the originally planned sparse experiments, inasmuch as the lateral resolution, ~10m, provides data needed to develop/test geoacoustic interpolation methods that will be required for 3D geoacoustic uncertainty models. The measurement and inversion techniques developed here could eventually become a highly useful tool for NAVOCEANO in building next generation seabed databases.

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